17 Managing Pacific Salmon Escapements: The Gaps Between Theory and Reality

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Abstract.—There are myriad challenges to estimating intrinsic production capacity for Pacific salmon populations that are heavily exploited and/or suffering from habitat alteration. Likewise, it is difficult to determine whether perceived decreases in production are due to harvest, habitat, or hatchery influences, natural variation, or some combination of all four. There are dramatic gaps between the true nature of the salmon spawner/recruit relationship and the theoretical basis for describing and understanding the relationship. Importantly, there are also extensive practical difficulties associated with gathering and interpreting accurate escapement and run-size information and applying it to population management. Paradoxically, certain aspects of salmon management may well be contributing to losses in abundance and biodiversity, including harvesting salmon in mixed population fisheries, grouping populations into management units subject to a common harvest rate, and fully exploiting all available hatchery fish at the expense of wild fish escapements. Information on U.S. Pacific salmon escapement goal-setting methods, escapement data collection methods and estimation types, and the degree to which stocks are subjected to mixed stock fisheries was summarized and categorized for 1,025 known management units consisting of 9,430 known populations. Using criteria developed in this study, only 1% of U.S. escapement goals are set by methods rated as excellent. Escapement goals for 16% of management units were rated as good. Over 60% of escapement goals have been set by methods rated as either fair or poor and 22% of management units have no escapement goals at all. Of the 9,430 populations for which any information was available, 6,614 (70%) had sufficient information to categorize the method by which escapement data are collected. Of those, data collection methods were rated as excellent for 1%, good for 1%, fair for 2%, and poor for 52%. Escapement estimates are not made for 44% of populations. Escapement estimation type (quality of the data resulting from survey methods) was rated as excellent for <1%, good for 30%, fair for 3%, poor for 22%, and nonexistent for 45%. Numerous recommendations for improvements in escapement mangement are made in this chapter. In general, improvements are needed on theoretical escapement management techniques, escapement goal setting methods, and escapement and run size data quality. There is also a need to change managers' and harvesters' expectations to coincide with the natural variation and uncertainty in the abundance of salmon populations. All the recommendations are aimed at optimizing the number of spawners—healthy escapements ensure salmon sustainability by providing eggs for future production, nutrients to the system, and genetic diversity.

INTRODUCTION

The recently documented declines in Pacific Northwest salmon populations (Nehlsen et al. 1991; Slaney et al. 1996; NMFS 1997) indicate a breakdown in the west coast salmon management paradigm. Salmon managers, harvesters, and the public face some challenging questions. Why are many Pacific Northwest salmon populations declining even though salmon managers use the best available management techniques? Are the current concepts of salmon management flawed? Is the gap between theoretical, scientific salmon management and the practical application of those theories so large that it often renders management ineffective? Why have these conditions persisted in salmon management despite clear and repeated warnings from scientists, most notably Larkin (1977), Wright (1981), Fraidenburg and Lincoln (1985), and Ludwig et al. (1993)? This review and analysis of the existing escapement management process may point to some solutions to these apparent dilemmas.

Although overharvest, dams, habitat degradation, hatcheries, and natural environmental fluctuations all have contributed to declines in Pacific salmon, the populations will not be sustainable without proper spawning escapements. *Sustainable* means providing the best possible economic and social benefits while maintaining natural biodiversity. Achieving sustainability will certainly require optimal escapements. *Optimal escapements* are those sufficient to fully realize the biological potential of the freshwater habitat, thereby maximizing smolt production.

Any meaningful discussion of Pacific salmon management must also be prefaced by definition of terms relevant to the stock concept. In this chapter, a *population* is defined as a spawning aggregation, having little interbreeding with other spawning aggregations other than the natural background stray rate, uniquely adapted to a spawning habitat, and inherently unique attributes (Ricker 1958) resulting in different productivity rates (Pearcy 1992; NRC 1996). A population is analogous to the spawning aggregations described by Baker et al. (1996) and the demes of NRC (1996). *Management units* are groups of one or more populations treated together for management purposes, such as executing fisheries, setting escapement goals, and estimating harvest rates.

In heavily exploited salmon populations and/or those suffering from habitat alteration, there is no adequate method to estimate the intrinsic production capacity or determine whether perceived decreases in production are due to harvest, habitat, hatchery influences, natural variation, or some combination of all four. (Even in an unexploited population, there is no known way to assess production capacity because there is no way to account for compensatory survival once harvest begins.) Until recently, the commonly accepted solution to this dilemma was to employ a spawner/recruit model (e.g., Ricker 1954), which expressed the relationship between the number of spawners and the resultant production of adult progeny (harvest plus returning spawners), while accounting for limitations in the productive capacity of the spawning environment. This model has been used to estimate population parameters such as optimum population size at maximum sustainable yield (MSY), optimum harvest rate at MSY, and the population size that produces maximum recruitment (Ricker 1975; Hilborn and Walters 1992). With these estimates, managers try to determine the harvestable surplus and the number of spawners required to perpetuate the population, referred to as the *escapement goal.*

In reality, however, estimates resulting from the spawner/recruit model can and do result in overharvest (NRC 1996). Deficiencies in the spawner/recruit approach fall into two broad categories: theoretical and practical. In the theoretical realm there are two major types of weaknesses. The first is that mathematical attempts to describe the actual productivity of the population have significant limitations (summarized by Hilborn and Walters 1992). The second is our inability to reasonably integrate the many effects of the salmon's environment into the spawner/recruit relationship (e.g., Drinkwater and Myers 1987; Walters and Collie 1988).

In the practical realm of salmon escapement management, deficiencies arise from a variety of interrelated sources. These include lack of or inaccurate catch and escapement data; institutional, political, and fiscal barriers preventing application of the most advanced run forecasting and inseason modeling; imprecise run-size predictions; inability of regulatory processes to keep abreast of changes in run abundance and harvesting efficiency as the run materializes in the various fishing areas; inability to account for varying freshwater and marine survival; and the effects of applying harvest management decisions to composite populations, where each population has a production capacity determined by its fitness and the environment (Wright 1981; Hilborn and Walters 1992; NRC 1996).

Because salmon management units often have been managed with some form of spawner/recruit model—typically only having population data from the exploited condition—and considering the deficiencies described above, escapement goals sometimes may have been set too low. Furthermore, in some populations, lower escapements have resulted in less nutrients (salmon carcasses) being transported into the system to support freshwater productivity and subsequent juvenile salmon production (Kline et al.1993; Bilby et al. 1996). This means there is a relationship between escapement and carrying capacity (i.e., escapement alone can influence the shape of the spawner/recruit curve).

The problems described above sometimes are further exacerbated when basic Ricker model concepts are applied in salmon management only loosely, i.e., without ensuring a rigorous modeling approach is used, but rather assuming that observed escapements are indicative of escapements at MSY if they appear stable (see, for example, Ames and Phinney 1977; Fried 1994). Since application of the spawner/recruit approach is limited, even under ideal circumstances, one can see why lax application of the concept can lead to inappropriate escapement goal setting.

Salmon harvest managers have used escapement goals as a method for setting the optimum or MSY population size and then determining the harvestable surplus each year. In some cases, particularly in abundant and stable populations, fixed escapement goals or a range of target escapements have worked well (e.g., Brennan et al. 1997). However, there are a number of management units for which escapement goals are not being met (e.g., Palmisano et al. 1993; WDFW and WWTIT 1994) and other management units in which the goals are being met but the habitat appears to have the capacity to produce larger runs (PFMC 1978; Hiss and Knudsen 1993; NRC 1996). Lack of salmon in salmon habitat cannot be completely explained by habitat destruction alone because some undamaged, unobstructed habitats are relatively void of salmon. Since salmon have a natural tendency to stray and colonize vacant habitat, as evidenced by the rapid colonization of habitats recently exposed by retreating glaciers in Glacier Bay, Alaska (Milner and Bailey 1989), one would expect to see fish straying into and colonizing unused habitats if they were available to do so.

There may also have been a tendency for escapement goals in some management units to evolve downward. Historic accounts of run sizes often indicate escapements and harvests were substantially greater than they are today. For one example, Fraser River sockeye runs were 25–35 million fish at the turn of the century but are presently managed for about 1–9 million fish (Collie and Peterman 1990). In another example, Chehalis River (Washington) chum salmon average run size was about 140,000 at the turn of the century but has averaged about 54,000 in recent years (Hiss and Knudsen 1993). Neither basin has had sufficient recent habitat degradation to fully explain the declines.

Escapement goals have sometimes been modified based on the spawner/recruit relationship of the most recent few years (e.g., Ames and Phinney 1977; Fried 1994). In some ways this can be an attempt to account for changing population structure. However, it may also be a response to a relatively short-term environmental influence combined with the socio-economic need for continued fishing (even though at low population levels, maintaining adequate escapement is most critical for continued population productivity). A spawner/recruit model of such a population, based on that same recent data only (i.e., without historic data at various population levels) would yield a lower escapement goal (Hilborn and Walters 1992). This example illustrates the misuse of spawner/recruit models.

Mixed population fisheries also complicate the attainment of adequate escapements in several ways. First, depending on how populations are grouped, a common harvest rate may result in overfishing less productive populations, since each population has an inherently different productivity rate (Pearcy 1992; NRC 1996). Second, when composite populations are harvested together, it is often difficult to apportion the catch to the various populations, making population-specific catch and run-size estimates difficult. The third problem resides in uncertainties about the influence of mixed populations, namely: difficulties in defining the uniquely adapted populations; the degree to which populations are grouped into management units; and difficulties in assessing productivity rates of individual populations. When populations are harvested together, it is more difficult to apportion the catch to the various populations, making population-specific catch and run-size estimates difficult or impossible (Mundy 1996). The most extreme impacts of mixed population fisheries occur where escapements for natural production have been severely reduced through harvest rates set so that hatchery fish can be fully harvested. This usually results in continual overharvest of wild fish (Hilborn 1992; NRC 1996).

The purpose of this chapter is to lay the groundwork for rebuilding and maintaining healthy Pacific salmon populations by identifying and describing the aspects of salmon escapement management presently precluding sustainability. I addressed the theoretical deficiencies of escapement management and developed a coastwide (but not exhaustive) collation and general analysis of information on the status of escapement management based on data provided by management agencies. Specific objectives of this study were to (1) identify and describe weaknesses in theoretical salmon management models and related weaknesses in setting escapement goals and estimating escapements; (2) determine whether some escapement goals have been gradually reduced over time; (3) summarize some effects of mixed population fisheries on escapements; and (4) make recommendations for improving escapements and escapement management.

METHODS

Weaknesses in theoretical escapement management were identified by reviewing the literature and developing a simple graphic illustration of the general concepts of why standard theoretical approaches to escapement management have been inadequate. For the remainder of the evaluation, information on escapement goal-setting methods and annual escapement estimation techniques was assembled and tabulated from the literature and through personal communications with agency management biologists. The general hypothesis that, for a significant proportion of management units and/or populations, there are serious deficiencies in the methods for setting escapement goals and estimating annual escapements was investigated by summarizing and categorizing escapement management information. A large spreadsheet table was prepared listing as many management units and populations as could be identified over a broad survey area covering much of Alaska, Washington, Oregon, and California. Escapement management information pertinent at the population or management unit level were incorporated into the table. The evaluation did not include data for hatchery populations or populations predominated by hatchery production, populations upstream of Bonneville Dam on the Columbia River, British Columbia, or the Arctic-Yukon-Kuskokwim area of Alaska. Every attempt was made to identify populations at their smallest, although biologically meaningful, level. However, this was not always possible, either because some populations were lumped by managers in their reports to me or because specific populations are yet to be differentiated. This means that my estimates of the number of populations were conservative.

Information on escapement goal-setting methods, escapement data collection methods, and escapement estimation types were subjectively and cursorily assigned to one of six categories, based on the availability and quality of the underlying methods and data. The classifications used in this study are described below.

Escapement Management

Escapement Goal-Setting Methods.—The methods used to set escapement goals for each management unit (groups of one or more populations) were categorized according to their degree of technical sophistication and likelihood of accurate representation of productivity, as follows.

Excellent method:

Combined-strong—a combination of methods, such as spawner/recruit modeling based on a comprehensive data record, with consideration for habitat production potential and allowance for annual variability, resulting in an accurate escapement goal.

Good methods:

Habitat-advanced—the escapement goal is based on a relatively sophisticated application of accurate habitat-based production potential;

Spawner/recruit—a spawner/recruit model is formally used to estimate the escapement goal; and

Historic—escapement goal based on some notion of what the escapements were prior to heavy exploitation.

Fair methods:

Combined-weak—escapement goal is based on a combination of methods, such as weak past escapement data combined with a general sense of habitat production potential;

Habitat—goal based on a generalized or somewhat outdated estimate of the watershed's carrying capacity; and

Recent escapements—escapement goal is based loosely on observed escapement data (e.g., average) or indices in the recent past (e.g., up to past 25 years).

Poor methods:

Index—escapement goal is set for one or more key populations within a management unit with an assumption that performance of the key population reflects performance of other populations within the unit.

No method:

No goal—no escapement goal set for the management unit.

No information:

No information available—Information available identifying management unit and sometimes the escapement goal but no information available as to how the goal is set.

For some management units, the escapement goal-setting method could have been classified into more than one of the methods defined above. If enough information was available, a management unit was categorized into the category best describing the escapement goal-setting method for that unit. The proportions of management units that fell into each category of escapement goal setting were then calculated to examine the extent of the gap between the best salmon population theory and its actual application in escapement goal management.

Gradual Escapement Goal Reduction.—There may be cases where the escapement goal has gradually been reduced over time in response to lower observed returns. This may occur when analysis of spawner/recruit data using recent data from a depressed population indicates an apparent steady state population, but which is unknowingly below carrying capacity, thereby resulting in underestimation of the escapement goal. I reviewed the literature to find cases where management policy had perhaps inadvertently contributed to declines in productivity and/or sustainability.

Estimating Annual Escapements.—Regardless of the run management method employed, the most basic data for evaluating management unit and/or population performance is the escapement estimate (plus catch data, which is outside the realm of this study). For management to be most successful, escapement estimates should be accurate and information should be collected at the population level. Therefore, the quality of coastwide escapement estimates was evaluated at the population level in two ways. First, escapement estimation was characterized in terms of the recent data collection methods for each population and classified generally as to the quality of that method. These included:

Excellent:
- Trap or dam count—A complete enumeration of all fish of the species and race passing a trap, weir, or dam;

Good:
- Dam or trap estimate—Partial observations and/or extrapolations of the run at a dam or estimates when a trap or weir is at times overtopped by high water;
- Tower—Estimates or total counts from a tower, bridge, or other visual observation point;
- Sonar—Estimates using sonar to count upstream migrants;

Fair:
- Mark-recapture—Run estimated using mark and recapture methods;
- Combined—Estimates or indices based on a combination of survey methods;

Poor:
- Foot index—Estimates or indices based on foot surveys;
- Aerial index—Estimates or indices based on aerial surveys;
- Boat index—Estimates or indices based on boat or drift surveys;
- Snorkel survey—Estimates or indices based on snorkel surveys;

None:
- None—no escapement estimate made for this population.

No information:
- No information available—Information available identifying the population but no information on whether or how the escapement is estimated.

Second, the type of count, estimate, or index resulting from the escapement data, and the relative quality of those statistics, was characterized for each population. Categories included:

Excellent:
- Total—A complete count of all individuals; only practically possible from dam or trap counts;

Good:
- Total estimate—An estimate based on an enumeration technique, i.e., counting and expanding (possible sources include dam or trap partial counts, tower, sonar, or mark and recapture);
- Peak count—based on repetitive survey of adults over the duration of the run, where the peak count or maximum fish days is ascertained and reported;
- Good index—Repetitive surveys within a season, utilizing an estimation technique such as area under the curve, but not expected to estimate total run due to variable visibility, etc. Surveys done annually either for entire stream or some consistent index reach(es).
- Total redds—Annually consistent program by some standard and calibrated method to either count all redds in a river or in a consistent index area;

Fair:
- One count—An annual survey done sometime during spawning with no way of knowing whether it was at the peak or not.
- Fair index—Similar to a Good Index (above) but lacking in either annual consistency or reliable visibility.
- Redd survey—survey one or more times to estimate total redds or redds/mile over some stretch(es) of river, but without rigorous validation or annual consistency;

Poor:
- One count-sporadic—Same as One count above but not done every year;
- Poor index—Similar to a Good Index (above) but having significant deficiencies in either annual consistency, data consistency, or reliable visibility; or
- Carcass index—survey one or more times to estimate carcasses/mile over some stretch(es) of river.

None:

None—no escapement estimate made for this population.

No information:

No information available—Information available identifying the population but no information on the type of escapement estimate, if any.

To better understand the effects that various data collection methods and types of escapement estimation surveys have on salmon escapement management, the information collected on the populations was summarized and used to assess the overall quality of escapement data collected in the western U.S.

Effects of Mixed Population Fisheries

If every population was a single management unit and was harvested separately from all other management units, life would be much simpler for salmon harvest managers. Unfortunately, most populations, and many management units, are harvested together in mixed population fisheries. Complete assessment of the extent of this fisheries management dilemma would require a unique and extensive study unto itself. However, assembly of the data described above provided an opportunity to conduct a cursory evaluation of the effects of mixed population fisheries on escapement. To assess the degree to which intraspecific mixed population fisheries were occurring, the number of populations within each management unit was summarized, by species and geographical area. Several case histories where decisions to forego wild production for full utilization of hatchery fish (the most extreme case of a mixed population fishery hindering natural escapements) were also reviewed and presented.

Results of the various evaluations described above were used to identify the successes and deficiencies of present management schemes and to make general recommendations regarding improvement of escapement goals and escapement management approaches.

RESULTS AND DISCUSSION

Theoretical Weaknesses

The inability of Pacific salmon management programs to in some cases prevent dramatic declines in populations can at least partly be attributed to theoretical deficiencies in widely used spawner/recruit models (NRC 1996). Although the models do provide a conceptual framework for considering management alternatives, they are often insufficient to support quality management due to inherent weaknesses and biases as well as inaccurate or sparse data (NRC 1996). Specifically, frequent and substantial errors in the numbers upon which models are based (namely, the counts or estimates of spawners, returning run sizes, and catches) can lead to overestimates of optimum harvest rate and underestimates of optimum population size, especially in overexploited populations (Hilborn and Walters 1992). Time-series bias of parameters can also develop in the models because size of recruitment depends to some extent on size of recruitment in the parent year (i.e., the independent variable is not actually independent). This can result in underestimation of optimum population size (Hilborn and Walters 1992). In addition, the stock/recruitment model assumes the relationship between spawners and subsequent run sizes does not change over time, but it does. This is particularly influenced by temporal changes in the population structure which can lead to models indicating a healthy population when, in fact, it is overexploited (Hilborn and Walters 1992). Gradual temporal shifts in the degree to which each environmental variable influences salmon survival render a model developed over a series of years less meaningful (biased) in subsequent years. Extreme interannual variation due to environmental influences leads to imprecision (poor fit) in the models. Furthermore, in exploited populations there are rarely extremely high escapements

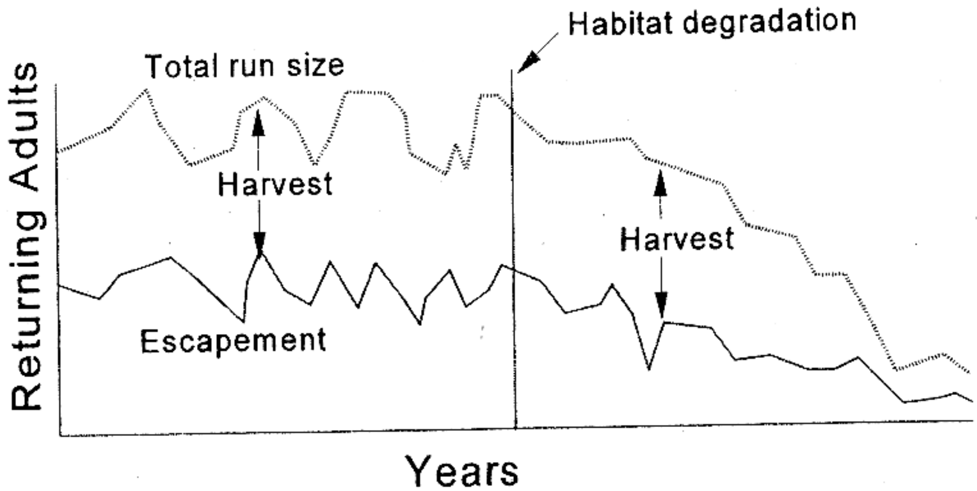

FIGURE 17.1 Hypothetical run size and escapement data from a salmon population under constant exploitation rate before (left of vertical line) and after (right of vertical line) habitat degradation begins in the watershed. Harvest is the difference between run size and escapement each year.

allowing assessment of the effects of large population on the stock/recruitment relationship (Hilborn and Walters 1992). This could also inadvertently lead to an underestimate of optimum population size and an escapement goal set too low.

Another serious challenge to the spawner/recruit model for managing Pacific salmon is that it does not adequately account for gradual habitat alterations nor can it discern whether changes in population abundance are due to habitat degradation or overfishing. A hypothetical data series is illustrated in Figure 17.1. During the years before habitat degradation (years for which there is usually no data), the population is in equilibrium, with steady-state exploitation that does not diminish the population. After habitat degradation begins, the population begins to decline. Assuming the harvestable surplus or harvest rate remains constant, which a spawner/recruit model based on previous years would support, the escapement and harvest begin to drop. Once the decline is underway, it is impossible to tell whether continuing losses are caused by habitat degradation or overfishing. It may have been, for example, that carrying capacity was only reduced somewhat, but that harvest rate either increased or, with decline in carrying capacity, the existing harvest level became too high for population perpetuation. Unfortunately, there is a time lag between when the carrying capacity is reduced and/or the harvest rate becomes too high and when the spawner/recruit model would indicate a recommended reduction in fishing effort. The biggest problem, however, is that once run sizes, escapements, and harvests have been reduced, the spawner/recruit model would indicate an escapement goal at some level below actual carrying capacity. For example, if a spawner/recruit model was developed based on the recent years of data (on the right in Figure 17.1), the escapement goal might be set lower than carrying capacity.

So one of the major flaws in salmon population models is that they assume a constant carrying capacity. To make matters worse, low escapements may be further diminished by the decreasing number of carcasses in the stream. Recent research demonstrates that a large proportion of productivity in healthy salmon streams is derived from nutrients in decaying salmon carcasses (Kline et al. 1994; Bilby et al. 1996). As the number of carcasses decreases, so does the biological carrying capacity, even when physical habitat is in good condition. If the physical habitat is simultaneously being degraded, it is impossible to discern whether the relative carrying-capacity reductions are due to habitat degradation, lack of carcass-transported nutrients, or both.

Oregon coastal coho historical catch and escapement data serve to illustrate that current "steady state" models do not reflect true production potential. Total run sizes have decreased to

10–20% of historical run sizes over the past 100 years or so (OFWC 1995, Figures 4a, 5a, and 7a), yet there is no information indicating the relative proportion of the long-term decline attributable to habitat degradation or overfishing (underescapement). What would production be like if escapements were of a historic magnitude, i.e., about ten or more times greater than today's? Of course, this unrealistically assumes pristine freshwater carrying capacity. However, since it is unlikely that freshwater habitat quality has been reduced 90% coastwide, as escapements have, ideal contemporary escapement goals probably lie somewhere between those observed today and ten times as much.

In summary, it seems that to pursue salmon management based solely on trying to improve the theoretical basis for standard spawner/recruit models and/or the accuracy and quality of data used in the models would be imprudent (NRC 1996). Because of significant uncertainty about factors influencing run sizes, even the best models simply will not perform to the degree that we can totally depend on them to accurately predict run sizes and, hence, catches. We will only make progress by finding new approaches that fully account for the influence of population abundance, habitat quality and carrying capacity, biological diversity, and variations in the marine and freshwater systems on the relationship between spawners and recruits. New models and approaches must also be addressed in an adaptive management framework (Walters 1986) and incorporate uncertainty in decision-making using some kind of decision theory (see, for example, Frederick and Peterman 1995; Adkison and Peterman 1996).

Escapement Management

Escapement Goal-Setting Methods.—Using the information from published and unpublished sources, I identified 1,025 wild or mostly wild U.S. management units (see Appendix Table 17.1). Some management units are not represented, particularly for California, the Arctic-Yukon-Kuskokwim area of Alaska, and the Columbia River upstream of Bonneville, but I believe about 90% of the U.S. coastwide units have been accounted for. Of the 1,025 documented units, I could not find information on how escapement goals have been set for 171 management units (17%) (Table 17.1). Of the 854 for which I had information, escapement goals for only 8 management units (1%) are set by methods that were rated as excellent, i.e., using methods that combined information in a way that most effectively characterizes the management unit's production potential (Table 17.1). Escapement goals for 142 management units (16%) were rated as good; they are set by either advanced consideration of habitat potential, spawner/recruit models based on fairly accurate run size estimates, or some notion of the historic production potential (Table 17.1). Fifty-eight percent (499) of management units have their goals set by methods rated as fair; using relatively inaccurate, habitat-based production potential, recent escapements, or some combination of the two. Escapement goal-setting methods for 13 management units (2%) were rated as poor; these were developed by monitoring one or several index streams representing a large number of populations in the same geographical area (Table 17.1). Escapement goals have not been established at all for 192 U.S. management units (22%). Together, this assessment shows that far too many management units are being managed with inappropriate, weak, or no goals.

To achieve fisheries sustainability, the methods for setting escapement goals must be improved. With 80% of management units having goals developed by fair or poor methods or having no goal, there is clearly a serious problem with the salmon management system. Furthermore, it must be remembered that escapement goal setting is done at the management unit level and many units are composed of multiple populations (reviewed below). Since individual populations may have varying production capacity (Pearcy 1992), it is likely that some management unit escapement goals could be inappropriate for individual component populations, resulting in chronic overharvest.

Gradual Escapement Goal Reduction.—A downward trend in escapements may result when overfishing and/or habitat degradation causes decreased population productivity and managers, basing their predictions for future productivity on recent low productivity, lower the estimated

TABLE 17.1
Summary of escapement goal setting methods for U.S. salmon management units.

Quality	Method	Chinook	Chum	Coho	Pink	Sockeye	Steelhead	All Species
		Species						
Excellent	Combined-strong	0	0	4	0	4	0	8
Good	Habitat-advanced	1	0	15	0	3	38	57
	Spawner/recruit	3	1	1	1	17	1	24
	Historic	14	12	1	26	8	0	61
Fair	Combined-weak	11	27	16	46	14	0	114
	Habitat	8	3	2	2	6	0	21
	Recent escapements	42	135	54	101	31	1	364
Poor	Index	2	0	4	1	6	0	13
No method	No goal	35	48	35	25	16	33	192
No information	No information	31	17	0	4	8	111	171

escapement goal. When, in the face of continued heavy harvest or habitat degradation, the population size is further reduced, managers are tempted to again lower the escapement goal, and so on. This occurs when, as is usually the case, the assumption of stable productivity is not met in spawner/recruit models (Hilborn and Walters 1992) and is exacerbated when analyses do not include an extensive historical record of population productivity. (Although revising the model to account for long-term changes in environment or habitat makes sense, differentiating between the sources of the changes, i.e., whether they are intractable or subject to human intervention, is impossible.)

An example of such a downward trend is the Klamath River chinook salmon, well documented in the beginning of its negative spiral by Fraidenburg and Lincoln (1985). As of 1978, the first year for which basin-wide escapement estimates were available, the escapement goal was 115,000 spawners, most of which were wild. In response to drought and overfishing, the Pacific Fishery Management Council (PFMC) adopted a 1980 "interim" escapement goal of 86,000 to prevent disruption of troll fisheries and cited a commitment to return to the original goal within 4 years. By 1983, PFMC had, in response to cries of economic hardship from user groups, adjusted the inriver run size target (escapement plus inriver catch) to 68,900 and the rebuilding schedule was lengthened to 16 years. Over the past few years, the escapement floor has been reduced to 35,000 with inriver run size (escapement plus inriver catch) targets set annually—in 1995 the target was 75,200 (PFMC 1996). The 1995 escapement exceeded the floor for the first time since 1989 (PFMC 1996). While this case provides an excellent example of how politics has influenced salmon management, it also illustrates how scientists and managers sometimes participate in regulating a fishery into overfishing.

Estimating Annual Escapements

Based on information collected from state biologists, I identified 9,430 discrete U.S. populations of Pacific salmon (see Appendix Tables 17.2 and 17.3). Based on my definition of a population, it was estimated that these 9,430 populations represent roughly two thirds of the wild or mostly wild U.S. Pacific salmon populations. There is little further information on the missing populations primarily because (1) populations are lumped together as reported by managers; (2) no work has been done to differentiate among populations; or (3) populations in some locations have not yet been documented.

Escapement Data Collection Methods.—Of the 9,430 identified populations, 6,614 (70%) had sufficient information to categorize the method by which escapement data have been collected (Table 17.2). Over 44% of populations (2,925) for which there is information are not monitored for escapement. Escapement data collection methods were rated as excellent for 79 U.S. populations (1%), where methods included total counts at dams, traps, or weirs. Methods were rated as good

TABLE 17.2
Number of U.S. populations for which each method of escapement estimation is used.

Quality	Method	Species						All Species
		Chinook	Chum	Coho	Pink	Sockeye	Steelhead	
Excellent	Dam count	9	0	2	0	0	0	11
	Trap count	5	6	21	20	16	0	68
Good	Dam or trap estimate	1	4	4	0	30	4	43
	Tower	1	0	0	0	5	0	6
	Sonar	0	0	1	0	4	0	5
Fair	Mark/recapture	0	0	0	0	1	0	1
	Combined	51	1	16	7	25	13	113
Poor	Foot survey	50	37	107	30	2	15	241
	Aerial survey	78	1230	744	928	197	18	3195
	Boat survey	3	0	0	0	0	0	3
	Snorkeling	0	0	0	0	0	2	2
None	No method	2	771	1733	0	84	335	2925
No information	No information	83	119	6	2418	7	184	2817

for 54 populations (1%); these methods included tower or sonar counts, or extrapolated estimates from trap, dam, or weir counts. Escapement data collection methods were fair for 114 populations (2%); these included mark and recapture methods and methods combining one or more survey types. Methods were poor for 3,441 populations (52%) and included individual survey types (foot, boat, aerial, snorkeling).

This summary was affected by several factors. First, the purpose was to generally characterize the quality of escapement data collection methods, not to be specific to locations. While recognizing that there are various possible criteria for categorizing and rating escapement data collection methods, the frame of reference for judging escapement data collection method quality in this study was a total count (i.e., the ideal escapement estimate). While some fishery managers may disagree with the categorizations, setting the quality categorizations relative to the ideal sets the tone for achieving sustainability. In regard to the outcome, even if all populations were upgraded by one category level, 96% of populations would still be rated as only fair or having no escapement estimation at all.

Second, the process of assigning the category for each run's escapement data collection method may have affected the summary. The quality of escapement data is strongly influenced by attributes like relative visibility, repetition, duration of annual survey records, and consistency of escapement estimation location and methods. Gathering information at that level of detail for each population would have been an insurmountable task, although more information was available for some populations than others, thereby allowing more accurate categorization. In most cases, however, my categorization decision was made based on limited information.

Third, the relative availability of information across populations affected the summary. It is possible that the information missing for 30% of the populations could skew the outcome of the summary one way or another. For example, the large number of Alaskan populations, mostly surveyed using aircraft (judged to be a poor method), tilted the overall outcome toward "poor" (see Appendix Table 17.2). On the other hand, of the Washington, Oregon, and California populations for which there was sufficient information, 93% were rated as having escapement estimation data collection methods rated as fair, poor, or non-existent (see Appendix Table 17.2). This suggests that the availability of information likely did not affect the summary outcome.

Even when these factors are considered, it remains obvious that both escapement data collection methods and the programs to collect high-quality escapement information are deficient. It is

TABLE 17.3
Number of U.S. populations for which each escapement estimation type is used.

		Species						
Quality	**Method**	**Chinook**	**Chum**	**Coho**	**Pink**	**Sockeye**	**Steelhead**	**All Species**
Excellent	Total	8	2	7	0	13	0	30
Good	Total estimate	13	258	27	514	52	5	869
	Peak count	88	252	106	462	109	0	1017
	Good index	12	0	29	0	0	6	47
	Total redds	7	0	7	0	0	0	14
Fair	One count	25	61	3	0	9	3	101
	Fair index	2	6	21	0	6	4	39
	Redd survey	17	0	21	0	0	15	53
Poor	One count—sporadic	1	680	644	0	90	17	1432
	Poor index	2	0	4	0	0	0	6
	Carcass index	9	0	0	0	0	0	9
None	No method	2	771	1733	0	84	335	2925
No information	No information	97	138	32	2427	8	186	2888

interesting to note that, while the NRC (1996) recommended adoption of a minimum sustainable escapement (MSE) approach and recommended more spawners in streams, they only indirectly alluded to the dearth of good quality escapement data essential for understanding the health of populations. Without improvements in the escapement monitoring system, achieving the laudable goals of MSE will be nearly impossible for many populations.

Escapement Estimate Type.—While the method of escapement data collection has important ramifications for the quality of the estimate, the type of estimate influences the quality of subsequent data analysis for run management. Of the 9,430 identified U.S. populations, 6,542 (69%) had sufficient information to categorize the type of escapement estimate (Table 17.3). Of the 6,542 populations, I rated 30 (>1%) as having excellent escapement estimation types; namely total counts. Escapement estimation types were rated as good for 1,947 populations (30%); they were based on total estimates extrapolated from dam, weir, sonar, or tower counts; peak counts derived from repetitive surveys; indices generated from reliable and consistent methods; or total redd counts based on some reliably calibrated method. Escapement estimate types for 193 populations (3%) were rated as fair; those based on one count per year, indices either not based on rigorous methodology or annually inconsistent, or surveys of redds not calibrated to estimate total production. Twenty-two percent of populations (1,447) have escapement estimate types considered to be poor; these estimates were based on one count per season but not in all years, loosely applied index areas, or based on carcass counts. No escapement estimation, therefore no estimation type, is generated for 2,925 populations (45%).

Since the ideal type of escapement estimate, a complete count, was set as the reference point for deciding how to categorize the quality of escapement estimation types, it could be argued that some types were underrated. However, even if some escapement estimation types were rated higher, most types would still be only fair. In terms of managing for sustainability, the goal should always be to acquire escapement counts or estimates that relate accurately to the harvest management processes used to set allowable catches.

The outcome of the escapement estimation type summary was strongly influenced by information availability. In particular, the large number of Alaskan populations, predominantly monitored by aerial surveys and rated as poor escapement estimation types (once per year, but sporadic, aerial indices), skewed the overall summary toward "poor." On the other hand, a large number of Alaskan populations are surveyed repetitiously each year allowing a "peak count," rated as good. The lack

TABLE 17.4
Number of populations per management unit, by U.S. state and species.

State	Species	Number of management units	Stocks per management unit
Alaska	Chinook	75	2.21
	Chum	159	12.67
	Coho	87	29.02
	Pink	193	17.56
	Sockeye	109	3.36
	Steelhead	7	48.00
Washington	Chinook	52	1.40
	Chum	82	1.77
	Coho	43	2.09
	Pink	13	1.08
	Sockeye	6	1.00
	Steelhead	92	1.25
Oregon	Chinook	12	2.92
	Chum	2	4.00
	Coho	2	9.50
	Steelhead	84	1.43
California	Chinook	7	1.00

of information about escapement estimation types may have also influenced the summary outcome. Perhaps additional information would have resulted in a somewhat different outcome.

Effects of Mixed Population Fisheries

The major effects of mixed population fisheries are experienced when fish from different populations, often having differing production capacities, are harvested simultaneously at the same harvest rate (NRC 1996). This can happen either with multiple wild populations or when hatchery populations are mixed with wild fish.

Number of Populations Within Management Units.—By summarizing the number of populations identified for each management unit (see Appendix Table 17.4), I was able to provide a minimal indication of the degree of mixed wild population fishery effects on populations. This is a minimal estimate because it does not account for interspecific mixed fisheries, nor fisheries where other management units are mixed with the management unit of interest, nor fisheries targeting hatchery populations.

In Alaska, chum, coho, and pink salmon and steelhead management units consist of a very large number of populations (Table 17.4). Much of this is largely influenced by Southeast Alaska and Prince William Sound where there are an extraordinary number of populations and where they are intentionally grouped together for management (Fried 1994; Baker et al. 1997; Van Alen 2000). Alaskan chinook and sockeye salmon management units averaged approximately three and four populations per management unit (Table 17.4).

In Washington, the average number of populations per management unit is less than in Alaska (Table 17.4). This is due partly to the smaller geographical area and easier access to most populations. However, the low numbers of populations per management unit may also be attributed to inadvertent or uninformed grouping of populations (as reported to me in the available information). For example, Hood Canal summer chum salmon are managed (secondarily to chinook and coho salmon) as four management units for which guideline escapement goals are set (PNPTC and WDFW 1995). Yet, spawning is known to occur in some 13 different locations which would result in a population to management unit ratio of 3.25 rather than the ratio of 1.77 based on published information or databases.

In Oregon chinook, coho, and chum salmon escapement goals are set for broad geographical groupings of populations (PFMC 1996), as indicated by high populations per management unit ratios (Table 17.4). The little information available for California chinook management units indicated they consisted of one population per management unit (Table 17.4).

The average number of populations per management unit varies widely among species and locations (Table 17.4). Much of this variation is likely due to differing management strategies for each species and the extent of the geographic area covered by the management agency. For example, many salmon and steelhead in Washington are managed on a population-by-population basis, whereas in Alaska, where there are tens of spawning streams within manageable geographical areas, very large numbers of populations are in some cases grouped together for management (Table 17.4). Alaskan managers reason that, because of the large numbers of spawning populations and the huge geographic areas, they have been successful at maintaining escapements by protecting near-terminal areas and moderating mixed population exploitation rates (e.g., Van Alen 2000).

My estimates of the numbers of populations per management unit are in many cases conservative for several reasons. First, I used only documented populations. There were cases where reports or databases indicated populations were grouped but there was no way to know which ones or how many. There were other cases where populations were grouped and I was not aware of it. I simply used the lowest published grouping level as the population.

Second, managers are only recently becoming aware of the appropriate spawning aggregation scale at which variability in productivity occurs (e.g., Varnavskaya et al. 1994). There is often a lack of definitive knowledge about population differences or, more critically, whether the populations have differing productivity rates. For one example, Alaska Department of Fish and Game sets one escapement goal for Kasilof River sockeye salmon and manages based on a spawner/recruit relationship (Fried 1994). However, recent studies are beginning to reveal that the Kasilof system sockeye run actually consists of several biologically unique populations (Burger et al. 1997; Woody 1998). A critical looming question in this and other similar cases is whether, having this new knowledge about smaller population units, harvest management could or should be changed to ensure abundance and biodiversity of all the populations.

Third, only intraspecific effects were considered. There are numerous cases where a secondary species is intercepted as by-catch during the prosecution of a fishery on a target species. This factor is not addressed in the foregoing summary but can have major impacts (e.g., Slaney et al. 1996).

In summary, many management units, upon which decisions are made, are composed of multiple populations (Table 17.4). The important consideration is that, when populations are grouped together for management, small and/or less productive populations may not be represented in the data and are at risk in light of high harvest rates set for larger and/or more productive populations (NRC 1996; Narver 2000). Small populations are at risk of being driven below a viable number of individuals and populations exhibiting low productivity are subject to chronic overharvest. As further testimony to this problem, it was clearly stated in recent status papers (Baker et al. 1996; Slaney et al. 1996) that many smaller populations were unaccounted for in their analyses. Trend analysis in those studies focused on the more abundant and productive populations, even though smaller or less productive populations are the most likely to be jeopardized first. Thus, those studies may have underestimated the risk to unmonitored populations. To achieve overall sustainability, it is always preferable to identify likely spawning aggregations as the smallest population unit, try to assess productivity at that level, and then develop management plans for protecting abundance and genetic diversity based on that knowledge. This does not necessarily rule out mixed population fisheries, but highlights the need for full understanding of the component populations being managed as a unit.

Harvest Priority for Hatchery Fish.—Extreme reductions in wild salmon escapements have occurred when intentional or inadvertent decisions have been made to prioritize harvest of hatchery fish over conservation of wild fish. Since management areas where this occurs can sometimes be quite extensive, the strategy can negatively affect a significant number of populations. Maximizing harvests of hatchery fish in mixed population fisheries often results in overharvest of wild fish and in large areas of potential salmon habitat being underutilized. Some noteworthy examples include Lower Columbia River coho salmon (WDF and WDW 1993), Willapa Bay salmon (PFMC 1994, NRC 1996) and Nooksack coho salmon (WDF et al. 1992) to name a few. The problem is not limited to the Pacific Northwest, but occurs in Alaska as well. For one example, increasing fishing effort on coho from Medvejie Hatchery in Southeast Alaska is resulting in a dramatic increase in harvest rate of wild Salmon Lake coho salmon which cannot be sustained (the harvest rate increased from 35% in 1985 to 72% in 1995, Schmidt 1996).

Effects of Run Management on Escapements.—While inseason run management is a complex topic unto itself and will not be treated in this study, it is important to recognize some of the ways that run management can influence escapements. These can include, but are not limited to: (1) socio-economic-political decisions affecting the setting of harvest rates, and, in turn, escapements; (2) managers being forced to provide proof there is overfishing rather than having to demonstrate there is a harvestable surplus above escapement needs; (3) allocation before escapements in many political jurisdictions; (4) scientists and managers becoming advocates of a fishery user group rather than advocates of the fish; and (5) uncertainty about population dynamics and harvest efficiency (Wright 1981; Fraidenburg and Lincoln 1985; Ludwig et al. 1993).

MANAGEMENT RECOMMENDATIONS

A variety of interrelated actions can be taken by fisheries managers, the public, and politicians to help achieve salmon sustainability through better escapement management, while additional remedial efforts are made in other areas (e.g., inseason run management, habitat protection and restoration, and hatchery program management). These recommended actions fall into three general categories: (1) improve the science of, and practical methods for, assessing escapements and setting goals; (2) ensure that escapements are sufficient to perpetuate maximum biomass production and biodiversity; or (3) change public attitudes and expectations about salmon production and fishing. The recommendations are summarized in Table 17.5; details follow.

Improve Escapement Management Technology

Theoretical salmon management must progress from being dependent upon the basic stock/recruitment model to new ways of expressing the natural cycles of salmon production, while accounting for human influences on salmon abundance (NRC 1996). The technology of escapement management can be improved by developing and testing new models for simulating and predicting salmon population dynamics, finding better ways to apply adaptive management, and incorporating decision theory and risk analysis. Research and development of escapement technology should be responsive to the needs of management agencies, perhaps coordinated by the Scientific Advisory Board recommended by NRC (1996).

Develop New Models.—There is an increasing call for salmon managers and scientists to move beyond the spawner/recruit modeling and rigid escapement goal setting used now, as these have not always provided the best management (NRC 1996) and have even led to erroneous conclusions and recommendations (Hilborn and Walters 1992). While present spawner/recruit modeling cannot yet be totally abandoned (because it is the best presently available and it takes time and money to replace the old models), scientists and managers should develop new models that better account for natural environmental variability and actual carrying capacity (when the freshwater habitat is fully seeded with carcasses). Several promising new models are worth investigation and further development; combinations of models may also warrant exploration.

TABLE 17.5
Summary of management actions which, taken in concert as necessary on a population-by-population basis, are likely to improve Pacific salmon escapements (see text for supporting explanations).

Improve Escapement Management Technology

- Develop new models
  - Habitat and environmental control models
  - Time and space models
  - Exploitation rate models
  - Decision theory
- Improve escapement estimation technology
- Improve population discrimination
- Increase research funding for population management

Ensure Healthy Escapements

- Identify and achieve "safe" escapement levels
- Collect accurate, consistent, and fully representative run size data
- Avoid the use of temporary escapement goals
- Reduce the number of populations per management unit
- Improve escapement goal setting methods
- Use smaller, more precise management areas
- Guard against gradual escapement goal reduction
- Improve harvest management
  - Reduce harvest rates
    - Reduce exploitation rates on all populations simultaneously in one fishery
    - Increase specificity of fisheries
    - Establish fishery refuges
    - Use selective fisheries
    - Invoke additional gear limitations
    - Increase use of limited entry
    - Buy back fishing boats and licenses
  - Accept "overescapement" at hatcheries
  - Use adaptive management
  - Settle Pacific Salmon Treaty allocation issues
  - Separate allocation issues from biological process

Change Public Attitudes and Expectations

- Improve public education
- Increase public involvement in the process
- Encourage harvesters to adapt to natural variation

- *Habitat and environmental control models.*—Production is normally limited by some combination of physical and biological carrying capacity, as influenced by climate and weather patterns. Models that incorporate such information and then examine the effects of human actions on production look promising for future salmon management. These have included Bayesian approaches (e.g., Hilborn et al. 1994; Geiger and Koenings 1991; Adkison and Peterman 1996), stochastic simulations (e.g., Cramer 2000), habitat-based approaches (e.g., Lestelle et al. 1996), and comprehensive planning approaches (e.g., Puget Sound Comprehensive Coho Program, CCW 1994). Whatever models are ultimately proven to be the best, they must incorporate terms to account for both marine and freshwater environmental variability. Walters and Parma (1996) have argued alternatively for fixed exploitation rate strategies wherein a percentage of the run is harvested regardless of run strength; this allows the escapement to track natural climatic variation. They postulated it may be more cost-effective to invest in research on how to implement fixed harvest rate strategies than on how to explain and predict climate effects.

- *Time and space models.*—Simulation models of fish populations as they migrate through time and space may help substantially in managing for better escapements because they will improve decisions about inseason management and/or help to evaluate consequences of alternative management scenarios. Several different approaches are being explored for quantifying the effects of migration, mortality, abundance, fishing effort, and gear types on fish abundance as they move through spatial cells or fishing districts (e.g., Walters et al. 1998; Lawson and Comstock 2000). "Nerkasim" is another promising technique, combining time and space attributes with environmental controls and individual fish bioenergetics (Rand et al. 1997).
- *Exploitation rate models.*—More work is needed on the effects of using exploitation rate models to set harvest rates, as described by CCW (1994), particularly regarding implementation of the same exploitation rate for mixed populations having varying productive capacities (i.e., variable spawner/recruit relationships). The degree to which spawners per recruit varies among neighboring populations is a central research question to be addressed before this approach can be fully implemented.
- *Decision theory.*—Researchers must continue investigating applications of decision theory and risk analysis (Walters 1986; Hilborn and Walters 1992) to salmon management. Subjecting the results of population/environmental modeling to decision analyses, as was done by Hilborn et al. (1994), in light of a variety of past management scenarios will allow testing of the predicted outcomes against reality and accounts for uncertainty in the management process.

Improve Escapement Estimation Technology.—As was seen in Tables 17.2 and 17.3, there is a great need for better escapement assessment and estimation techniques. Further research is needed in the areas of survey design, stratified sampling (e.g., Irvine et al. 1992), area under the curve techniques (e.g., English et al. 1992), remote sensing such as video and hydroacoustic techniques (e.g., Hatch et al. 1994), mark and recapture (e.g., Schwarz et al. 1993), or other as yet untried methods.

Improve Population Discrimination.—The ability to separate populations in fisheries is critical to managers wanting to direct or control harvest on specific populations. Salmon population composition is usually accomplished by genetic analysis (e.g., Carvalho and Hauser 1994), tag recoveries (e.g., Cormack and Skalski 1992), or by scale pattern recognition (e.g., Marshall et al. 1987). All of these processes currently have drawbacks in timeliness or cost that prevent managers from making expedient decisions to open or close fisheries. More technological research is needed to develop improved or new population discrimination techniques that can be rapidly applied inseason. Furthermore, much work is needed to establish baseline population differences, both in technology development and in practical research on population discrimination within management units. Debate will continue on the relevance of discriminating among populations at the finest scale, but I contend the critical question is whether biologically discernable populations have differing productivity rates; if so, they should either be managed separately from neighboring populations or as a group but with a conservative exploitation policy.

Increase Research Funding for Population Management.—There is a pressing need for improvements in technology for understanding, enumerating, predicting, and managing salmon runs. The NRC (1996) identified many critical gaps in knowledge, many of which are relevant to escapement management. The federal government presently supports most of the basic research that is conducted—that should continue and increase. However, it is also important that states and user groups provide contributions to research funding. Research on escapement management should be of particular relevance to states, since they are the primary escapement managers. While the costs for additional research may seem prohibitive, long-term recovery and sustainability may be worth the price, just as it has been for other depleted fisheries such as the Atlantic coast striped bass *Morone saxatilis* (Field 1997).

Ensuring Healthy Escapements

Increasing escapements of depleted populations and maintaining adequate escapements of healthy populations are the quickest ways to realize conservation goals (Riddell 1993) and should be the ultimate goal of fishery managers trying to achieve sustainability. As stated by NRC (1996), a shift must be made from focusing on catch to focusing on escapement. Salmon managers should be required to provide evidence that a population is healthy enough to allow a fishery rather than having to prove the population may be jeopardized by overfishing before curtailing fishing (Wright 1981). Several authors have demonstrated the concept that, in many cases, fishing less (increasing escapement) can result in larger catches in the long term (Hilborn and Walters 1992; NRC 1996). Optimal escapements are numbers that not only perpetuate the population and ensure biodiversity (Riddell 1993), but also provide enough carcasses to maximize the carrying capacity potential of the system. The goal should be to identify the appropriate harvest rate in light of each population's naturally varying mortality schedule. There are a number of specific fishery management recommendations that support sustainability through increasing and optimizing escapements.

Identify and Achieve "Safe" Escapement Levels.—As recommended by NRC (1996), the concept of MSY should be replaced with minimum sustainable escapements (MSE) for as many populations as possible. Rather than selecting a specific escapement goal, about which target escapements fluctuate, as has been done in the past, the MSE is an escapement level which should always be met. Most importantly, escapements should range well above the MSE. This will enhance productivity and biodiversity by allowing for years in which so-called excess escapement builds resiliency into the system, supplies abundant carcasses (nutrients), and allows for sufficient escapements of any smaller, weaker populations within the management unit. Further work will be required to estimate how much escapements should range above MSE.

Since salmon survival is intimately dependent on highly variable ocean conditions, it is critical that we ensure adequate escapements in years of poor ocean productivity (poor marine survival). It is important to remember, for example, that short-term upswings in apparent abundance may result from variation in marine production rather than improvements due to habitat changes or improvements in escapement management (see, for example, Lawson 1993).

Collect Accurate, Consistent, and Fully Representative Run Size Data.—Regardless of the theoretical modeling approach employed for data analysis and run prediction, basic data collection will always be a critical component of the salmon management process. Although this chapter is about escapement, it is essential that consistent data be collected on all aspects of the run size, including both catch and escapement. As can be seen in the summary of escapement estimation (Table 17.2), the majority of populations have poor or no escapement data. Management agencies need to increase emphasis on escapement assessments, as well as other critical population-specific data.

In large, remote areas, where it is impractical to survey escapement of every population, it is vitally important to routinely and accurately assess the status of populations of a range of sizes and productive capacities. Escapement assessment programs should be designed to include intensive monitoring of small and less productive populations in approximately the proportion that they occur naturally. In this way, early warnings can be raised when these important components of the population structure are thought to be jeopardized.

Avoid the Use of Temporary Escapement Goals.—Managers should also avoid the use of "interim," "target," "phased-in," "gradual," "eventual" or other short-term escapement objectives when dealing with depressed salmon populations because they tend to lead to deliberate overfishing of salmon runs (Wright 1981). For any salmon run returning at or below the level required for MSE, all target fisheries must be closed. There is no viable alternative (Wright 1981). In addition, management options to reduce incidental harvest should be invoked.

Reduce the Number of Populations per Management Unit.—Whenever possible, it is preferable that escapement goals be established for individual populations, i.e., in the context of this chapter, that each population become a management unit. This will help reduce the effects of mixed population fisheries on small or less productive populations. Whether the fisheries on these populations can actually be managed to harvest each population separately is a separate issue (addressed below); the salient point is that managers must understand how many populations occur within a management unit, the natural productivity of each population, and how fisheries are influencing their total production and viability.

Improve Escapement Goal-Setting Methods.—The results of this evaluation show that there are a large number of management units for which there are poor or no escapement goals, even when populations are combined (Table 17.1). I recommend that MSE (NRC 1996) be applied to all possible populations. This will require additional funding and personnel to implement but is essential for future sustainability. As new management technology develops and better information is collected for each unit, the goals should be refined. Escapement goal setting will also benefit from related improvements in escapement, stock discrimination, coded wire tag, age structure, smolt productivity, and habitat utilization data.

Use Smaller, More Precise Management Areas.—One way to gradually move salmon management toward sustainability is to decrease the size of some fishing management areas or districts. While this is now mostly limited by the inability to discern which populations of fish are being harvested in each area and the time required for processing information from the fishery to managers, I believe we should be striving in many fisheries for managing time and location of fishery openings on a smaller, more expedient scale. As the technical ability to rapidly process population discrimination information is further developed, fisheries can be opened in smaller areas or times to harvest any abundant populations and closed in areas to protect weak populations. More opportunities will be available for opening fisheries on discrete, abundant populations when management areas are smaller.

Guard against Gradual Escapement Goal Reduction.—Managers, decision-makers, and users should be vigilant against the temptation to reduce escapement goals. As described in detail above, standard spawner/recruit models can give the illusion that MSY will be attained with a lower escapement goal, particularly when based on recent population performance (Hilborn and Walters 1992). While there is often remarkable pressure from users, and the concomitant desire of fishery managers to satisfy constituents, decision-makers should require hard evidence that "excessive" escapements are actually reducing productivity before a goal or MSE is lowered.

Improve Harvest Management.—There is also a group of harvest management actions which can help to achieve healthy escapements, either by reducing the effects of mixed population fisheries or simply ensuring additional fish escape to the spawning grounds.

- *Reduce harvest rates.*—Reducing harvest rates where necessary will increase abundance (i.e., long-term catch) on strong populations (e.g., Cramer 2000), revitalize depleted populations, and protect weaker populations. Because abundant and depleted (or susceptible) populations are often mixed together in fisheries, it is important that management allow for separate harvest regimes for strong and weak populations (NRC 1996). Several recent cases demonstrate how reduced harvest rates have benefited escapement, particularly of smaller populations. In 1995, for example, Canada's Department of Fisheries and Oceans recognized the emergency nature of coho off the west coast of Vancouver Island and reduced the harvest rate from the previous 60 to 80% down to about 50%, increasing escapements of coho to Carnation and Clemens creeks at least tenfold (Tschaplinski 2000). Reduced harvest rates in many other locations will undoubtedly increase the size and diversity of spawning populations, as recommended by NRC (1996).

The following management actions can be applied, in various combinations on a case by case basis, to reduce harvest rates and/or the effects of mixed population fisheries.

Reduce exploitation rates on all populations simultaneously in one fishery.—Closing or reducing effort in mixed population fisheries, as necessary, will protect weak populations and allow more productive populations to pass to the next fishery for either harvest or escapement. It is recognized this may result in short-term disruptions and complications to the economic and social infrastructure of salmon-based economies (NRC 1996), but will improve the chances of sustaining production of all populations for the long-term benefit of society.

Increase specificity of fisheries.—Some fisheries can and should be managed with more specific time and area openings and closings to control how they influence populations migrating through management areas. That way, weak populations can be protected when they are mixed with strong ones, but strong populations can be harvested as they separate from others during migration. This strategy will result in a larger emphasis on terminal fisheries, not only providing harvest opportunities and weak population protection, but with the added advantage of more accurate documentation of fishing mortality (Mundy 1997). It must be noted, however, that these shifts will have their own harvest management challenges and cause disruptions to the existing salmon fishery social and economic infrastructure.

Establish fishery refuges.—It may be preferable to close some harvest management areas for the long term. These may be areas where a large number of particularly sensitive populations congregate. This will also result in larger catches in terminal fishing areas.

Use selective fisheries.—Selective fisheries have been recommended as one method of effectively harvesting strong populations while allowing others to escape (Lincoln 1994). There are a number of gear and management options that can be combined to create selective fisheries. A most popular option being proposed and investigated is the fin-clipping of all hatchery-reared coho and chinook salmon (Lawson and Comstock 2000). Non-clipped, wild fish could be released from non-lethal fisheries, such as purse seines, trollers, sport, live traps, and fish wheels, while all fin-clipped fish could be retained. Fishers using those same gear types could also retain or release fish on a species-by-species basis as necessary.

Invoke gear limitations.—Use of less selective gears, such as gill-nets in certain fisheries, should be reduced or eliminated except in areas where it is demonstrated that they have no impact on weak populations. This again could have significant implications for existing salmon fisheries.

Increase use of limited entry.—Most salmon fisheries are already limited (NRC 1996). There is some hope that individual transferable quotas (ITQs) may provide incentive for harvesters to limit catches when run sizes are low (e.g., Fujita and Foran 2000). Since ITQs apply to specific runs, ITQ holders may recognize that an investment in future production (i.e., by sometimes reducing or eliminating fishing effort in the short term) will increase their catches in the longer term.

Buy back fishing boats and licenses.—Although buy-back programs have been implemented in certain fisheries in the past with mixed success, it is still a viable option to help reduce the potential effort in certain fisheries (NRC 1996) and the pressure on managers to open fisheries on populations that cannot withstand fishing mortality.

- *Accept "overescapement" at hatcheries.*—In areas currently managed for hatchery harvest rates, exploitation should be reduced to allow sufficient natural spawners to fully seed all available habitat. This may result in so-called overescapement of hatchery fish unless they can be harvested in a terminal area where they are separated from wild fish. In cases where too many hatchery fish might result in negative ecological or genetic impacts in the adjoining habitat, it might be preferable to reduce the hatchery program so that it simply augments wild production. If programs can be developed to market the excess hatchery salmon carcasses, then another plausible strategy might include fishing at the rate sustainable by the natural population while harvesting all excess at the hatchery rack. Some combination of these alternatives should allow hatchery production beyond what would be produced from wild production alone while protecting and maximizing wild production.

- *Use adaptive management.*—The principal of adaptive management (Walters 1986; Hilborn and Walters 1992) should be applied to as many management units as possible. This is because, regardless of the methods presently used or those to be used in the future, managers need to evaluate the success or failure of the variety of management alternatives that are intentionally or inadvertently invoked. Managers should follow the six steps of adaptive management (Walters 1986; Hilborn and Walters 1992), making new decisions each year using decision theory and evaluating the consequences of those decisions.
- *Settle Pacific Salmon Treaty allocation issues.*—Although an updated Pacific Salmon Treaty (PST) was recently signed, it would be naive not to recognize problems caused in past U.S. and Canadian escapement management by the inability to resolve international allocation issues. Many of the other recommendations in this chapter need to be implemented by one country to benefit populations originating in the other country and vice versa. The challenges of the PST have been discussed in detail by other authors (e.g., NRC 1996). Suffice to say that resolution of these international issues is essential to the future of all salmon populations originating in one country and migrating through the other country's fisheries.
- *Separate allocation issues from biological process.*—Fishery biologists charged with determining whether there is a harvestable surplus should not also be involved in allocation decisions. Biologists should be free to make recommendations of escapement levels or harvest rates necessary to maintain abundant populations and biological diversity. They should also make recommendations about whether there is a harvestable surplus and when and where the surplus will be available with the least impact on other populations. This information should then be provided to the political process for final allocation decisions. The Alaskan management process has generally worked well locally and serves as a good model (Holmes and Burkett 1996).

Change Public Attitudes and Expectations

Until recently, the general goal of fisheries management was to stabilize fisheries so that user groups could count on a certain level of harvest and stable income. While there may be some viable strategies to reduce the likelihood of closed fisheries (such as fishing regimes based on steady, but most likely lowered, harvest rate) salmon managers, harvesters, and the public may ultimately benefit by accepting that salmon abundance follows natural, often extreme, cycles (Cramer 2000). This means that user groups should be encouraged to adjust to fluctuations in fish availability and income. There are several ways salmon managers can assist in disseminating this message, thereby helping to ease the negative ramifications of the natural downswings in salmon abundance.

Improve Public Education.—Salmon managers and scientists should help people understand the concepts of (1) variable productivity; (2) less fishing can mean more fish over the long term; (3) the importance of large escapements to long-term productivity; (4) the connections between human population growth (and associated impacts) and salmonid populations; and (5) the importance of genetic and population biodiversity. This can be accomplished through public forums and workshops and by incorporating these concepts into high school curricula.

Public education of salmon harvesters and recreational users will help to support increased funding for research and management. As a negative example of how this feedback loop functions, notice how, as soon as fish become unavailable, the users tend to blame government managers for ineptness. Yet, agency funding is continually being reduced in state legislatures, preventing scientists and managers from conducting the research and basic data collection so desperately needed to support quality run size predictions and escapement management. An informed public will pressure legislators to support and fund the necessary programs.

Increase Public Involvement in the Process.—There has been much discussion and progress toward an ecosystem-based, community approach to watershed management and salmon restoration (e.g., Lichatowich et al. 1995; Bingham 2000; Fields 2000; MacDonald et al. 2000). Yet these new public processes have usually failed to incorporate salmon production, escapement, and harvest management, primarily because harvest management remains the realm of agency and tribal fisheries managers. When salmon user groups and watershed landowners and citizens have the opportunity to hear all the evidence presented by harvest management biologists, and have the chance to voice their opinions about decisions, they may become more invested in the outcome of decisions and the status of the resource upon which they vitally depend (e.g., Riddell 1993). The salmon ecosystem extends from the ridgetops to the high seas. Watershed-oriented discussions designed to benefit salmon should include all stakeholders, cover all portions of the salmon ecosystem and all impacts along the way, and particularly include the effects of harvest and harvesters.

Encourage Harvesters to Adapt to Natural Variation.—A major public paradigm shift is particularly required, wherein all users' and managers' expectations are modified to coincide with the variable and unpredictable nature of salmon populations. Protection of the spawning escapement (the investment principle) must be given the highest priority (NRC 1996), rather than maximizing the catch. This may require significant economic and social adjustments because fishing patterns will necessarily be variable from year to year, resulting in disruptive and unpredictable employment patterns. However, if coastal communities can adapt to the variation, the pay-offs in improved long-term productivity will be substantial.

In closing, although it is obvious that invoking all these escapement management recommendations will be very expensive, the long-term economic, social, and cultural costs of not doing so (i.e., further depleting salmon populations and/or production) will be greater. Furthermore, voluntary, proactive implementation of these measures will forestall the otherwise inevitable, involuntary restrictions resulting from further Endangered Species Act listings or, worse, the eventual loss of additional populations. To truly achieve Pacific salmon sustainability depends on a public commitment to invest in expanded salmon research, management, and public education. We cannot count on repairing only one damaged aspect of salmon runs (e.g., degraded habitat) to fix the problem, but must work on all fronts simultaneously. Ultimately, though, both productivity and biodiversity depend on sufficient escapement of spawners to fully utilize the available freshwater habitat, fertilize the systems with carcasses, and optimize genetic diversity.

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APPENDIX TABLE 17.1

Summary of escapement goal-setting methods for U.S. salmon management units, by species and state (or Alaskan region).

Quality	Method	Species						All
		Chinook	Chum	Coho	Pink	Sockeye	Steelhead	Species
		Alaska (Alaska Peninsula/Aleutian Islands)						
Excellent	Combined-strong							0
Good	Habitat-advanced					2		2
	Spawner/recruit							0
	Historic	1				3		4
Fair	Combined-weak		9		16			25
	Habitat					4		4
	Recent escapements	4		5		3		12
Poor	Index							0
No method	No goal	1	3	4	4	5		17
No information	No information							0
		Alaska (Bristol Bay)						
Excellent	Combined-strong							0
Good	Habitat-advanced							0
	Spawner/recruit	1			1	9		11
	Historic							0
Fair	Combined-weak	1		3				4
	Habitat							0
	Recent escapements	1						1
Poor	Index							0
No method	No goal	25	24	10	9	9		77
No information	No information							0
		Alaska (Chignik)						
Excellent	Combined-strong							0
Good	Habitat-advanced							0
	Spawner/recruit					2		2
	Historic		5		5			10
Fair	Combined-weak							0
	Habitat							0
	Recent escapements	1						1
Poor	Index							0
No method	No goal			2				2
No information	No information							0
		Alaska (Cook Inlet)						
Excellent	Combined-strong					3		3
Good	Habitat-advanced							0
	Spawner/recruit							0
	Historic	3		1				4
Fair	Combined-weak	2	14		30	12		58
	Habitat							0
	Recent escapements	20		6		1		27
Poor	Index							0
No method	No goal							0
No information	No information							0

APPENDIX TABLE 17.1 (continued)
Summary of escapement goal-setting methods for U.S. salmon management units, by species and state (or Alaskan region).

Quality	Method	Species						All
		Chinook	Chum	Coho	Pink	Sockeye	Steelhead	Species
		Alaska (Kodiak)						
Excellent	Combined-strong							0
Good	Habitat-advanced							0
	Spawner/recruit					5		5
	Historic					5		5
Fair	Combined-weak					1		1
	Habitat							0
	Recent escapements	3	77	41	100	26		247
Poor	Index							0
No method	No goal		7	6	6	1		20
No information	No information		1			4		5
		Alaska (Prince William Sound)						
Excellent	Combined-strong					1		1
Good	Habitat-advanced					1		1
	Spawner/recruit					1		1
	Historic		7		16			23
Fair	Combined-weak	1						1
	Habitat							0
	Recent escapements	1		2		2		5
Poor	Index							0
No method	No goal							0
No information	No information							0
		Alaska (Southeast)						
Excellent	Combined-strong							0
Good	Habitat-advanced							0
	Spawner/recruit	1						1
	Historic							0
Fair	Combined-weak	3		1				4
	Habitat		2	2	2	1		7
	Recent escapements	3						3
Poor	Index			4	1	6		11
No method	No goal		10					10
No information	No information	3			3	1	7	14
		Washington						
Excellent	Combined-strong			4				4
Good	Habitat-advanced			16			38	54
	Spawner/recruit	1					1	2
	Historic	3			5			8
Fair	Combined-weak	1	4	12		1		18
	Habitat	8	1			1		10
	Recent escapements	9	59		1		1	70
Poor	Index	2						2
No method	No goal	2	3	12	6	1	33	57
No information	No information	28	16	1	1	3	20	69

APPENDIX TABLE 17.1 (continued)

Summary of escapement goal-setting methods for U.S. salmon management units, by species and state (or Alaskan region).

Quality	Method	Species: Chinook	Chum	Coho	Pink	Sockeye	Steelhead	All Species
		Oregon						
Excellent	Combined-strong							0
Good	Habitat-advanced							0
	Spawner/recruit		1	1				2
	Historic	7						7
Fair	Combined-weak	3						3
	Habitat							0
	Recent escapements							0
Poor	Index							0
No method	No goal	2	1	1				4
No information	No information						84	84
		California						
Excellent	Combined-strong							0
Good	Habitat-advanced	1						1
	Spawner/recruit							0
	Historic							0
Fair	Combined-weak							0
	Habitat							0
	Recent escapements	1						1
Poor	Index							0
No method	No goal	5						5
No information	No information							0

APPENDIX TABLE 17.2

Number of populations, by species and state (or Alaskan region), for which each method of escapement estimation is used.

Quality	Method	Species: Chinook	Chum	Coho	Pink	Sockeye	Steelhead	All Species
		Alaska (Alaska Peninsula/Aleutian Islands)						
Excellent	Dam count							0
	Trap count					2		2
Good	Dam or trap estimate							0
	Tower							0
	Sonar							0
Fair	Mark/recapture							0
	Combined							0
Poor	Foot survey							0
	Aerial survey	11	117	20	300	51		499
	Boat survey							0
	Snorkeling							0
	Test fishing							0
None	No method							0
No information	No information		1	3				4

APPENDIX TABLE 17.2 (continued)
Number of populations, by species and state (or Alaskan region), for which each method of escapement estimation is used.

Quality	Method	Species						All
		Chinook	Chum	Coho	Pink	Sockeye	Steelhead	Species
		Alaska (Bristol Bay)						
Excellent	Dam count		0					0
	Trap count							0
Good	Dam or trap estimate							0
	Tower					5		5
	Sonar			1				1
Fair	Mark/recapture							0
	Combined	2	1	1	3	4		11
Poor	Foot survey							0
	Aerial survey	29	24	9	7	9		78
	Boat survey							0
	Snorkeling							0
	Test fishing							0
None	No method			2				2
No information	No information							0
		Alaska (Chignik)						
Excellent	Dam count							0
	Trap count							0
Good	Dam or trap estimate	1				2		3
	Tower							0
	Sonar							0
Fair	Mark/recapture							0
	Combined			1				1
Poor	Foot survey							0
	Aerial survey		48	3	48			99
	Boat survey							0
	Snorkeling							0
	Test fishing							0
None	No method							0
No information	No information							0
		Alaska (Cook Inlet)						
Excellent	Dam count							0
	Trap count							0
Good	Dam or trap estimate			1		4		5
	Tower							0
	Sonar					3		3
Fair	Mark/recapture							0
	Combined	8		3	4	5		20
Poor	Foot survey	2	3	3	15			23
	Aerial survey	15	11		12	4		42
	Boat survey							0
	Snorkeling							0
	Test fishing							0
None	No method							0
No information	No information							0

APPENDIX TABLE 17.2 (continued)
Number of populations, by species and state (or Alaskan region), for which each method of escapement estimation is used.

Quality	Method	Species						All Species
		Chinook	Chum	Coho	Pink	Sockeye	Steelhead	
		Alaska (Kodiak)						
Excellent	Dam count							0
	Trap count	3	4	14	20	14		55
Good	Dam or trap estimate							0
	Tower							0
	Sonar							0
Fair	Mark/recapture							0
	Combined							0
Poor	Foot survey		1	33	15	1		50
	Aerial survey		86	24	138	28		276
	Boat survey							0
	Snorkeling							0
	Test fishing							0
None	No method							0
No information	No information			3		1		4
		Alaska (Prince William Sound)						
Excellent	Dam count		0					0
	Trap count							0
Good	Dam or trap estimate					1		1
	Tower							0
	Sonar					1		1
Fair	Mark/recapture							0
	Combined	1				16		17
Poor	Foot survey							0
	Aerial survey	9	202	30	419	3		663
	Boat survey							0
	Snorkeling							0
	Test fishing							0
None	No method							0
No information	No information		1					1
		Alaska (Southeast)						
Excellent	Dam count							0
	Trap count	2		4				6
Good	Dam or trap estimate		4	2		23	2	31
	Tower							0
	Sonar							0
Fair	Mark/recapture					1		1
	Combined	19		3				22
Poor	Foot survey					1		1
	Aerial survey	12	742	658	3	102	18	1535
	Boat survey							0
	Snorkeling							0
	Test fishing							0
None	No method	1	770	1707		84	316	2878
No information	No information	51			2405			2456

APPENDIX TABLE 17.2 (continued)
Number of populations, by species and state (or Alaskan region), for which each method of escapement estimation is used.

Quality	Method	Species: Chinook	Chum	Coho	Pink	Sockeye	Steelhead	All Species
		Washington						
Excellent	Dam count			2				2
	Trap count		2	3				5
Good	Dam or trap estimate			1			2	3
	Tower							0
	Sonar							0
Fair	Mark/recapture							0
	Combined	21		8			13	42
Poor	Foot survey	19	25	52			15	111
	Aerial survey	2			1		1	4
	Boat survey	3						3
	Snorkeling						2	2
	Test fishing							0
None	No method		1	24			19	44
No information	No information	30	117		13	6	64	230
		Oregon						
Excellent	Dam count	6						6
	Trap count							0
Good	Dam or trap estimate							0
	Tower							0
	Sonar							0
Fair	Mark/recapture							0
	Combined							0
Poor	Foot survey	29	8	19				56
	Aerial survey							0
	Boat survey							0
	Snorkeling							0
	Test fishing							0
None	No method							0
No information	No information						120	120
		California						
Excellent	Dam count	3						3
	Trap count							0
Good	Dam or trap estimate							0
	Tower	1						1
	Sonar							0
Fair	Mark/recapture							0
	Combined							0
Poor	Foot survey							0
	Aerial survey							0
	Boat survey							0
	Snorkeling							0
	Test fishing							0
None	No method	1						1
No information	No information	2						2

APPENDIX TABLE 17.3
Number of populations, by species and state (or Alaskan region), for which each escapement estimation type is used.

Quality	Method	Species: Chinook	Chum	Coho	Pink	Sockeye	Steelhead	All Species
	Alaska (Alaska Peninsula/Aleutian Islands)							
Excellent	Total							0
Good	Total estimate					2		2
	Peak count	10	115	18	294	51		488
	Good index							0
	Total redds							0
Fair	One count							0
	Fair index							0
	Redd survey							0
Poor	One count—sporadic							0
	Poor index							0
	Carcass count							0
	Carcass index							0
None	No method							0
No information	No information	1	3	5	6			15
	Alaska (Bristol Bay)							
Excellent	Total							0
Good	Total estimate	2		2	2	8		14
	Peak count	26	25	9	8	10		78
	Good index							0
	Total redds							0
Fair	One count	3						3
	Fair index							0
	Redd survey							0
Poor	One count—sporadic							0
	Poor index							0
	Carcass count							0
	Carcass index							0
None	No method			2				2
No information	No information							0
	Alaska (Chignik)							
Excellent	Total							0
Good	Total estimate	1	48	1	48	2		100
	Peak count							0
	Good index							0
	Total redds							0
Fair	One count			3				3
	Fair index							0
	Redd survey							0
Poor	One count—sporadic							0
	Poor index							0
	Carcass count							0
	Carcass index							0
None	No method							0
No information	No information							0

APPENDIX TABLE 17.3 (continued)
Number of populations, by species and state (or Alaskan region), for which each escapement estimation type is used.

		Species						All
Quality	Method	Chinook	Chum	Coho	Pink	Sockeye	Steelhead	Species
		Alaska (Cook Inlet)						
Excellent	Total							0
Good	Total estimate	3		4	31	10		48
	Peak count		14					14
	Good index							0
	Total redds							0
Fair	One count	22						22
	Fair index			3		6		9
	Redd survey							0
Poor	One count—sporadic							0
	Poor index							0
	Carcass count							0
	Carcass index							0
None	No method							0
No information	No information							0
		Alaska (Kodiak)						
Excellent	Total					13		13
Good	Total estimate	3	3	14	14			34
	Peak count		88	35	159	29		311
	Good index							0
	Total redds							0
Fair	One count					1		1
	Fair index							0
	Redd survey							0
Poor	One count—sporadic							0
	Poor index							0
	Carcass count							0
	Carcass index							0
None	No method							0
No information	No information			25		1		26
		Alaska (Prince William Sound)						
Excellent	Total							0
Good	Total estimate		203		419	3		625
	Peak count	10		30		18		58
	Good index							0
	Total redds							0
Fair	One count							0
	Fair index							0
	Redd survey							0
Poor	One count—sporadic							0
	Poor index							0
	Carcass count							0
	Carcass index							0
None	No method							0
No information	No information							0

APPENDIX TABLE 17.3 (continued)
Number of populations, by species and state (or Alaskan region), for which each escapement estimation type is used.

Quality	Method	Species: Chinook	Chum	Coho	Pink	Sockeye	Steelhead	All Species
		Alaska (Southeast)						
Excellent	Total	2		1				3
Good	Total estimate		4	6		27	2	39
	Peak count	19		14	1	1		35
	Good index							0
	Total redds			2				2
Fair	One count		61			8	1	70
	Fair index							0
	Redd survey	2						2
Poor	One count—sporadic		680	644		90	17	1431
	Poor index							0
	Carcass count							0
	Carcass index							0
None	No method	1	770	1707		84	316	2878
No information	No information	61	1		2407	1		2470
		Washington						
Excellent	Total		2	6				8
Good	Total estimate						3	3
	Peak count	1	2					3
	Good index	12		10			6	28
	Total redds	7		5				12
Fair	One count						2	2
	Fair index	2	6	18			4	30
	Redd survey	14		21			15	50
Poor	One count—sporadic	1						1
	Poor index	2		4				6
	Carcass count							0
	Carcass index	3						3
None	No method		1	24			19	44
No information	No information	33	134	2	14	6	66	255
		Oregon						
Excellent	Total	6						6
Good	Total estimate							0
	Peak count	22	8					30
	Good index			19				19
	Total redds							0
Fair	One count							0
	Fair index							0
	Redd survey	1						1
Poor	One count—sporadic							0
	Poor index							0
	Carcass count							0
	Carcass index	6						6
None	No method							0
No information	No information						120	123

APPENDIX TABLE 17.3 (continued)
Number of populations, by species and state (or Alaskan region), for which each escapement estimation type is used.

Quality	Method	Species: Chinook	Chum	Coho	Pink	Sockeye	Steelhead	All Species
				California				
Excellent	Total							0
Good	Total estimate	4						4
	Peak count							0
	Good index							0
	Total redds							0
Fair	One count							0
	Fair index							0
	Redd survey							0
Poor	One count—sporadic							0
	Poor index							0
	Carcass count							0
	Carcass index							0
None	No method	1						1
No information	No information	2						2

APPENDIX TABLE 17.4
Number of management units and stocks per management unit for each U.S. state (or Alaskan region) and species.

State or region	Species	Number of management units	Number of populations	Stocks per management unit
Alaska (Alaska Peninsula and Aleutian Islands)	Chinook	6	11	1.8
	Chum	12	118	9.8
	Coho	9	23	2.6
	Pink	20	300	15.0
	Sockeye	17	53	3.1
Alaska (Bristol Bay)	Chinook	28	31	1.1
	Chum	24	25	1.0
	Coho	13	13	1.0
	Pink	10	10	1.0
	Sockeye	18	18	1.0
Alaska (Chignik)	Chinook	1	1	1.0
	Chum	5	48	9.6
	Coho	2	4	2.0
	Pink	5	48	9.6
	Sockeye	2	2	1.0
Alaska (Cook Inlet)	Chinook	25	25	1.0
	Chum	14	14	1.0
	Coho	7	7	1.0
	Pink	30	31	1.0
	Sockeye	15	16	1.1
Alaska (Kodiak)	Chinook	3	3	1.0
	Chum	85	91	1.1
	Coho	47	74	1.6
	Pink	106	173	1.6
	Sockeye	43	45	1.0
Alaska (Prince William Sound)	Chinook	2	10	5.0
	Chum	7	203	29.0
	Coho	2	30	15.0
	Pink	16	419	26.2
	Sockeye	5	21	4.2
Alaska (Southeast)	Chinook	10	85	8.5
	Chum	12	1516	126.3
	Coho	7	2374	339.1
	Pink	6	2408	401.3
	Sockeye	8	211	26.4
	Steelhead	7	336	48.0
Washington	Chinook	52	75	1.4
	Chum	82	145	1.8
	Coho	43	90	2.1
	Pink	13	14	1.1
	Sockeye	6	6	1.0
	Steelhead	92	115	1.2
Oregon	Chinook	12	35	2.9
	Chum	2	8	4.0
	Coho	2	19	9.5
	Steelhead	84	120	1.4
California	Chinook	7	7	1.0

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BACK COVER: (TOP LEFT): Blake Covernton, Pro Plan Services: Commercial salmon troller; **(TOP RIGHT):** Blake Covernton, Pro Plan Services: Martin Andrew of the Boothroyd Band, dipnetting and transport of sockeye salmon past a landslide on the Nahatlatch River; **(CENTER):** George Gatenby, Sports Fisherman: Catch and release of 30 lb King salmon; **(BOTTOM):** Mike Galesloot, Nesconlith Indian Band/Shuswap Nation Fisheries Commission: Coho enumeration efforts in the Thompson River watershed.

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